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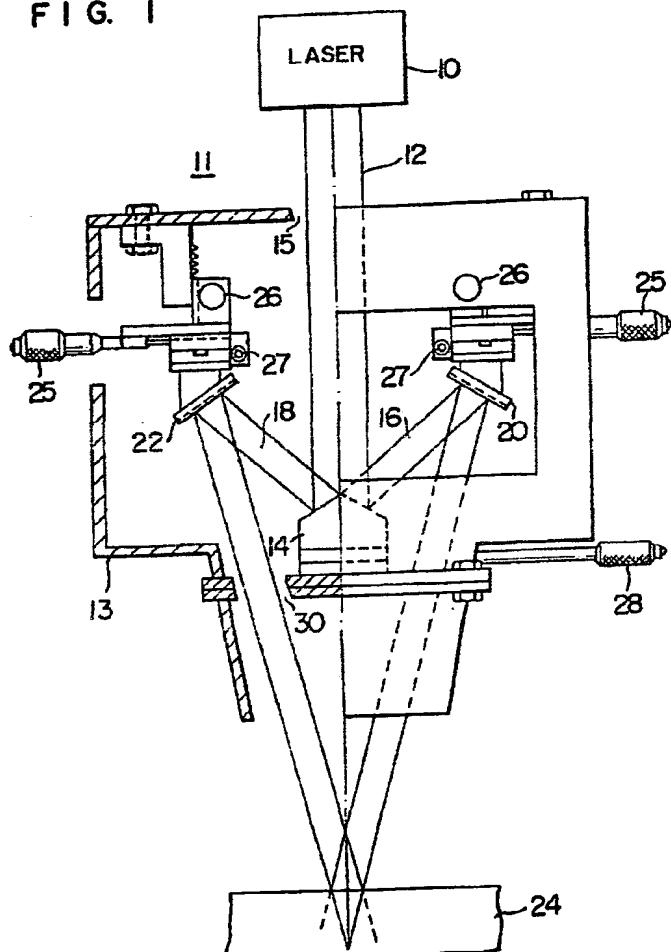
(74) Agents

Langner Parry

(54) Method of treating object by laser beam and apparatus therefor

(57) A laser beam 12 emitted from a laser apparatus 10 is divided at 14 into a plurality 16,18 of fractional beams, and the fractional laser beams are reflected at 20,22 toward and irradiated on an area to be irradiated of an object being treated, such that energy density distribution on the irradiated area is made substantially uniform in at least one direction.

FIG. 1

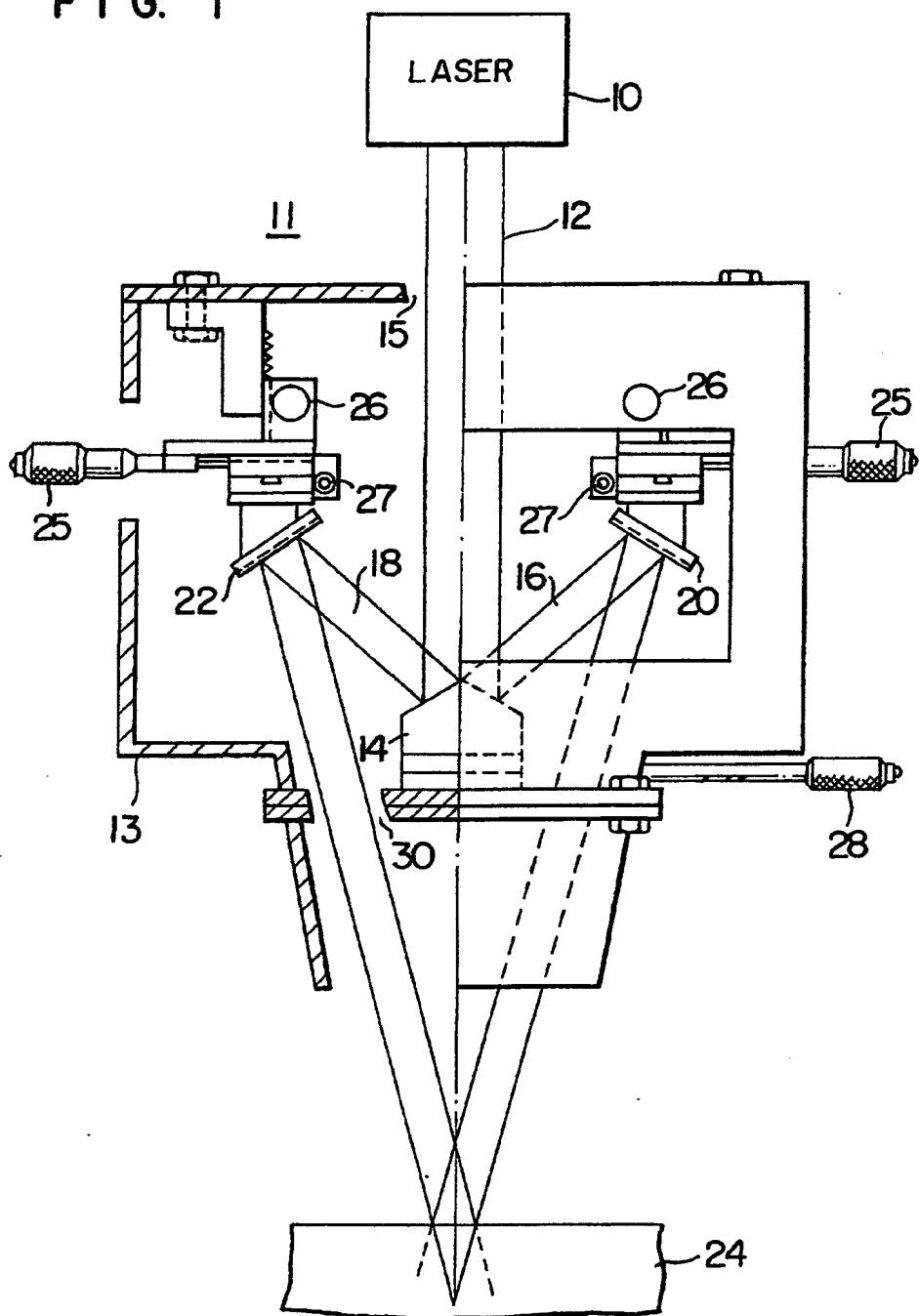


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FIG. 2

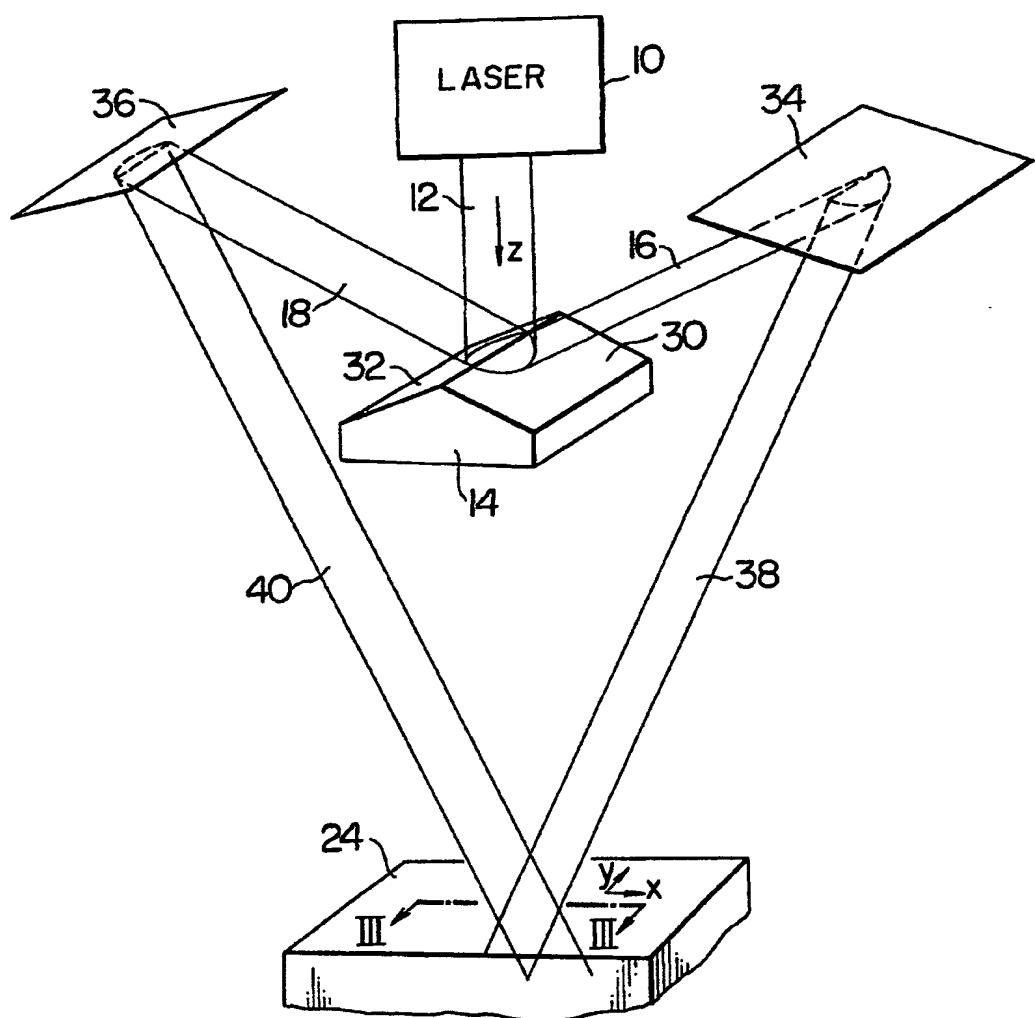
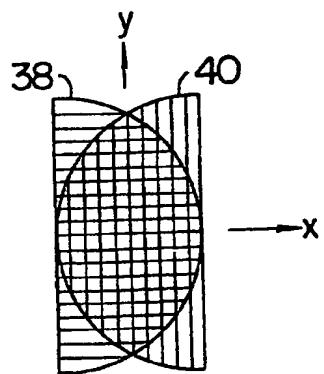


FIG. 3



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FIG. 4

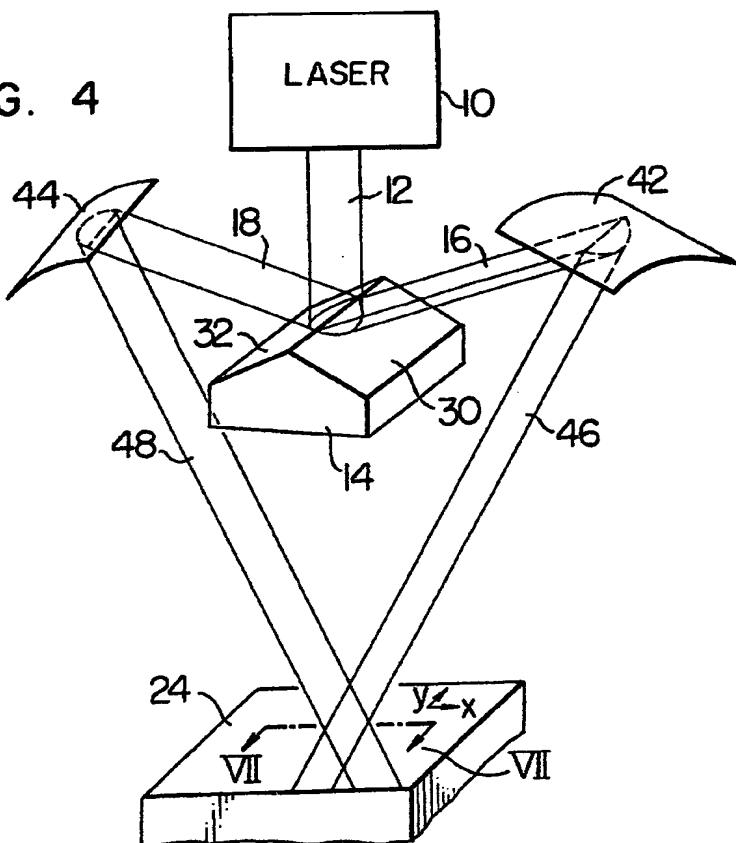


FIG. 5

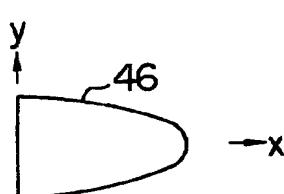


FIG. 6

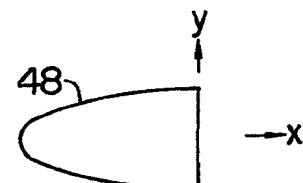


FIG. 7

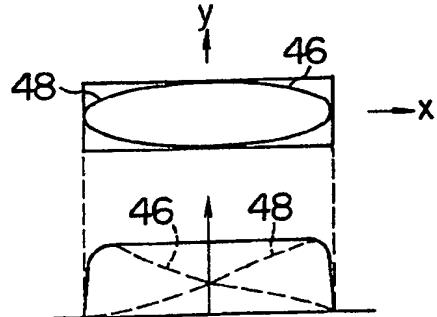


FIG. 8

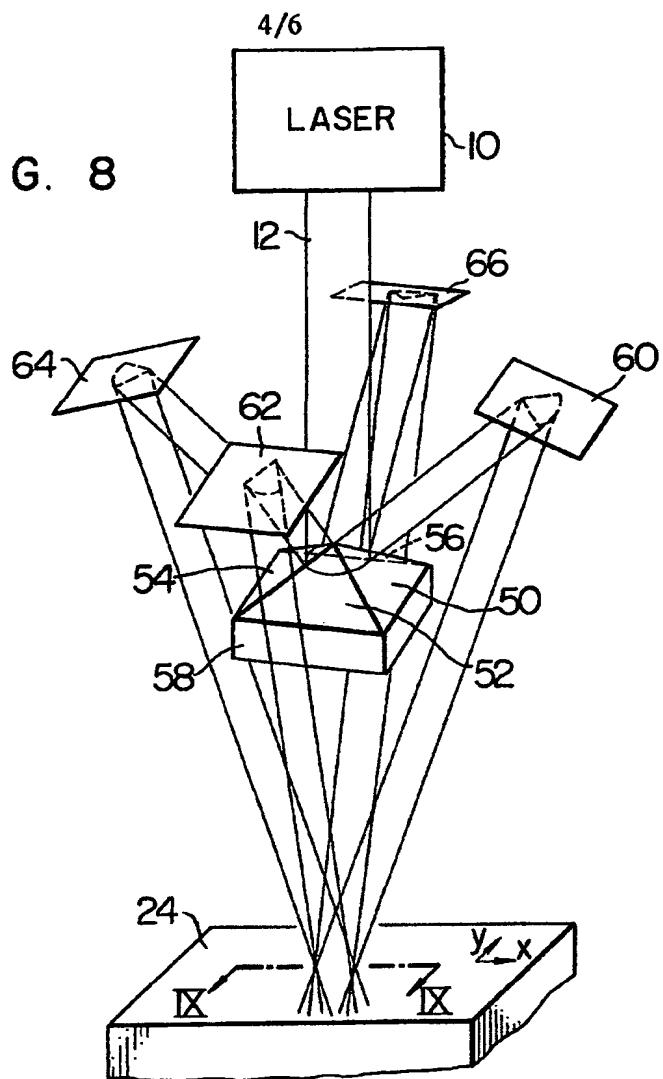


FIG. 9

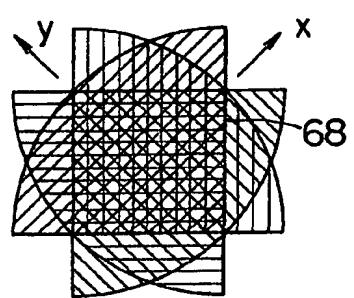


FIG. 10

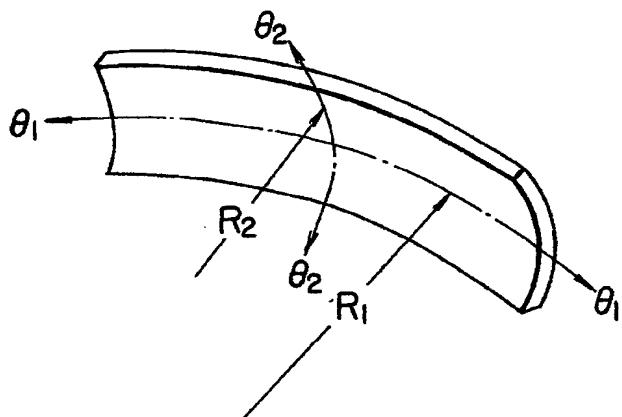


FIG. 11

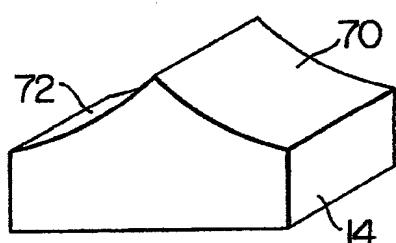


FIG. 12

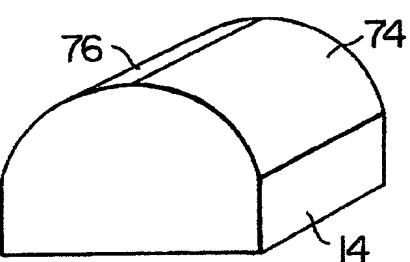


FIG. 13

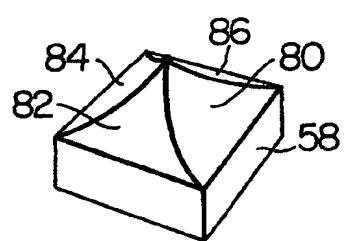
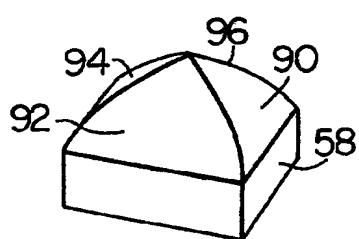


FIG. 14



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FIG. 15

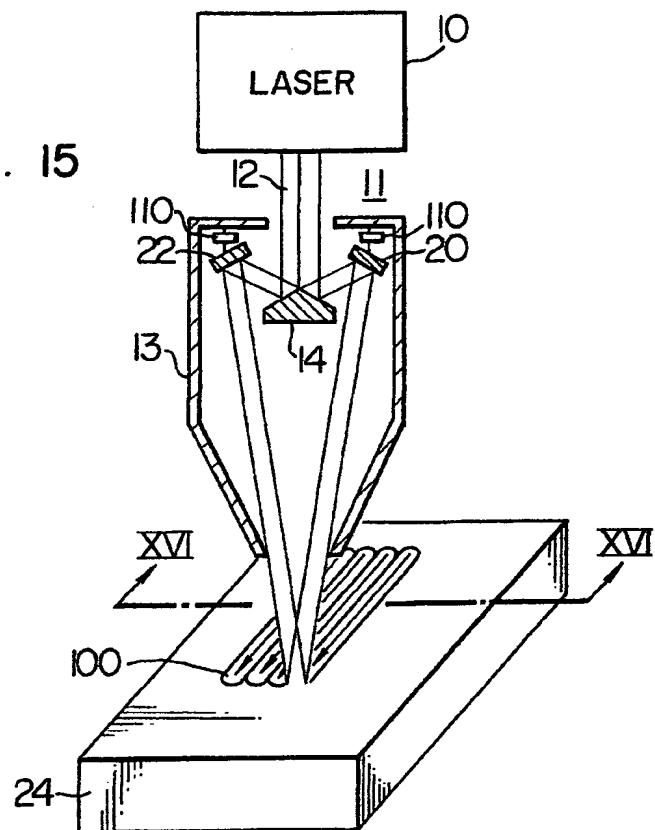
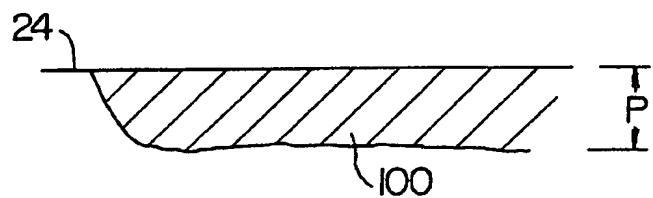


FIG. 16



SPECIFICATION**Method of treating object by laser beam and apparatus therefor**

5 The present invention relates to a method of treating an object by a laser beam and an apparatus therefor in which the object to be treated is irradiated by the laser beam, and more particularly to the
 10 method and apparatus being capable of providing a laser beam of a uniform energy density distribution suitable for a thermal treatment of the object and making the entire irradiation energy substantially uniform on every individual unit areas on the
 15 irradiated surface of the object to be treated.

Energy density of a laser beam taken out from a laser apparatus usually has a distribution subject to various modes depending on characteristics of the laser apparatus. Namely, intensity distribution of
 20 the laser beam on a cross-sectional plane perpendicular to the beam transmission shows a specific pattern, that is a mode pattern, depending on the characteristics of the laser apparatus.

Where the laser beam thus produced is irradiated
 25 on an object to be treated to carry out a surface thermal treatment such as a surface quenching, surface alloying and the like, uniformity of energy density distribution on the beam crosssection is first required. Taking a laser beam in TEM₀₀ mode subject to a Gaussian distribution, for example, the energy density is high at the center of the circular beam cross-section and decreases exponentially as it deviates from the center. Namely, energy is most concentrated in the vicinity of the optical axis.
 35 When the laser beam with this distribution is focused through a focusing lens and is then irradiated on the surface of the object to be treated, the laser energy is concentrated to a central portion of the irradiated area. Consequently, the temperature
 40 in the central portion is raised so excessively that the material at the central portion is vaporized, leaving behind a recess and/or cracks. This prevents ideal surface quenching and surface alloying.

Next to the aforementioned requirement, in the
 45 surface thermal treatment of interest, it is necessary to make uniform the entire amount of energy irradiated on every individual unit areas on the irradiated surface of the object to be treated. Suppose now that a laser beam having a uniform energy density distribution over its circular cross-sectional area can be obtained by any suitable means and this laser beam is scanned in one direction in order to thermally treat, for example, to quench a relatively large area on the surface of an object to be
 55 treated. In such a case, since the cross-section of the laser beam irradiated on the object is circular, the portion of the irradiated surface through which the central portion of the beam passes receives more energy than the portion of the irradiated surface
 60 through which the peripheral portion of the beam passes, thereby making it difficult to heat uniformly every portion of the surface to be treated.

Various methods have hitherto been proposed to
 65 provide a laser beam of a uniform energy density

distribution. They are classified into two major types of which one intends to adjust the density distribution by means of an optical system and the other intends to so modify the construction of laser apparatus per se as to solve the problem in question.

As a method of adjusting the laser beam energy density distribution by means of an optical system, a filter method, so to speak, may first be mentioned

70 75 which is disclosed in Japanese Patent Publication No. 26,075/71 published July 28, 1971, for example. According to the method disclosed therein, a filter having a less light transmittivity at its central portion than at the other portion is disposed on a
 80 light path of a Gaussian type laser beam to thereby uniform the energy density distribution of the laser beam which has passed through the filter. Next, reference is made to a so-to-speak optical scattering method as announced in Data Sheet No. 511 entitled 'Optical Integrators' issued March, 1975 by SPAWR Optical Research, Inc., of the United States of America and as disclosed in Japanese Patent Publication No. 5,665/69 published March 10, 1969. The former employs a downward-tapered rectangular reflector having a square cross-section hollow whose inner surface serves as a reflecting surface. A laser beam focused by a spherical, concave reflecting surface is led through an upper opening of the hollow reflector to the inner reflecting surface
 90 95 face to be reflected therewith several times so that the laser beam is scattered to uniform the energy density distribution, and the scattered laser beam is again focused by a second spherical, concave reflecting surface to be irradiated on an object. On the other hand, the latter attains a uniform energy density distribution by rotating a laser beam having an ununiform energy density distribution, around the optical axis.

100 105 As a method of modifying the construction of the laser apparatus per se to meet uniformity of the energy density distribution of the emitted laser beam, a proposal by GTE Sylvania Inc. of the United States of America is mentioned. In a catalog issued February 1, 1977 by GTE Sylvania Inc. is disclosed a
 110 CO₂ laser, Model 975 having a rated high output power of 5 KW, which emits a circular beam having a great number of peaks of energy density distribution which are substantially uniformed as a whole.

The aforementioned filter method of Japanese
 115 Patent Publication No. 26,075/71 has a disadvantage that a great deal of laser energy is lost. The proposal by SPAWR Optical Research Inc. is successful in obtaining a laser beam of square cross-section having a uniform energy density distribution but is disadvantageous in that the beam cross-section is excessively widened and also prevented from being focused in one direction for the sake of providing a narrow-width, stripe beam, resulting in poor efficiency of surface thermal treatment. In the
 120 125 method of Japanese Patent Publication No. 5,665/69 a laser beam to be irradiated on the surface of the object being treated is of a circular cross-section but such a laser beam itself, as described above, cannot afford to uniform the entire amount of irradiation energies on individual unit areas on

the irradiated surface. In addition, this method has difficulties with focussing the beam in one direction to provide a narrow width beam. The proposal by GTE Sylvania Inc. inevitably requires a laser apparatus of a large output capacity and also encounters the same problem as mentioned above arising from the circular cross-section of the beam.

The present invention intends to obviate the aforementioned prior art disadvantages and has its object to provide a method of treating an object by a laser beam and an apparatus therefor, which can easily provide a laser beam of substantially uniform energy density distribution and unify the entire amount of irradiation energy on individual unit areas on the irradiated surface of an object to be treated.

According to one aspect of the present invention, there is provided a method of treating an object by a laser beam in which the object to be treated is irradiated by the laser beam comprising the steps of emitting the laser beam from a laser apparatus, dividing the laser beam into a plurality of fractional laser beams, and irradiating the plurality of fractional beams on an area to be irradiated of the object to be treated after compounding the plurality of fractional beams such that energy density distribution on the irradiated area is made substantially uniform in at least one direction.

According to another aspect of the present invention, there is provided an apparatus for laser beam treatment comprising means for generating a laser beam, means for dividing the laser beam into a plurality of fractional laser beams, and means for irradiating the plurality of fractional beams on an area to be irradiated of an object to be treated after compounding the fractional beams such that energy density distribution on the irradiated area is made substantially uniform in at least one direction.

The present invention will be described in more detail by way of preferred embodiments by referring to the accompanying drawings in which

Figure 1 is a partially cross-sectional elevation view to show an overall construction of an apparatus for laser treatment embodying the present invention;

Figure 2 is a schematic, diagrammatic representation useful to explain the principle of an embodiment of a method for a laser treatment according to the present invention;

Figure 3 is a plan view to show a cross-sectional configuration of a laser beam on an object to be treated according to the embodiment of *Figure 2*;

Figure 4 is a schematic, diagrammatic representation useful to explain the principle of another embodiment of the laser treatment method according to the present invention;

Figures 5 and 6 are plan views to respectively show a cross-sectional configuration of the respective fractional laser beams according to the embodiment of *Figure 4*;

Figure 7 is a diagram to show a cross-sectional configuration and an energy density distribution of laser beam irradiated on an object to be treated according to the embodiment of *Figure 4*;

Figure 8 is a schematic, diagrammatic represen-

tation to show a construction of a further embodiment of the laser treatment method according to the present invention;

Figure 9 is a diagram to show a cross-sectional configuration of a laser beam irradiated on an object to be treated according to the embodiment of *Figure 8*;

Figure 10 is a perspective view to show a modified embodiment of a reflecting mirror for dividing a laser beam and compounding the fractional laser beams;

Figures 11 to 14 are perspective views to show various modified embodiments of reflecting mirror for dividing a laser beam;

Figure 15 is a perspective view to show an apparatus for laser treatment embodying the present invention which was used to treat an object as an experiment; and

Figure 16 is a diagram to show a quenched region in the object treated according to the apparatus of *Figure 15*.

Referring to *Figure 1* generally showing an overall construction of an apparatus for laser treatment according to the present invention, the apparatus

comprises a laser apparatus 10 for generating a laser beam 12, and a head generally designated at 11 and having a protective cover or housing 13. The laser beam 12 is led to the interior of the head through a laser beam inlet opening 15 of the head.

The laser beam 12 is reflected at two reflecting surfaces of a mirror 14 to be divided into two fractional beams 16 and 18. The two fractional beams 16 and 18 are respectively led to reflecting mirrors 20 and 22, preferably in the form of a concave surface of

second degree, and reflected there at toward a laser beam outlet opening 30 of the housing 13 so as to be compounded on an area to be irradiated of an object 24 being treated. Dividing mirror and reflecting mirror position adjusters 25, 26, 27 and 28 are

adapted to adjust the projection of the fractional beams reflected from the reflecting mirrors 20 and 22 such that the fractional beams are compound on a desired location of the object 24 being treated. To this end, the adjusters 26, 25 and 27 are respective-

ly designed for adjusting the respective reflecting mirrors 20 and 22 to displace in the direction in which the laser beam 12 travels (hereinafter referred to as z-direction), to displace in the direction of the ridge line between the two reflecting surfaces

of the dividing mirror 14 in a plane perpendicular to the z-direction (hereinafter referred to as y-direction), and to displace in the direction perpendicular to the y-direction in the plane perpendicular to the z-direction (hereinafter referred to as x-direction). The adjuster 28 serves to displace the dividing mirror 14 in the y-direction.

A preferred embodiment of the present invention is based on a principle as detailed below.

Referring to *Figure 2*, in a first embodiment of the present invention, a laser beam 12 emitted from a laser apparatus 10 and having a Gaussian energy density distribution is irradiated on a gable-roof-like dividing mirror 14 having two plain reflecting surfaces 30 and 32 such that the diametral center line of the laser beam cross-section coincides with

ridge line of the mirror 14 in order to ensure that the laser beam 12 is divided into two similar fractional laser beams 16 and 18. The two fractional laser beams 16 and 18 are reflected at two reflecting mirrors 34 and 36 to travel on such paths as beams 38 and 40 do. To ensure that the reflected fractional beams 38 and 40 are compounded with respective cross-sectional configurations of fractional laser beams 38 and 40 positioned in a relation as shown in Figure 3 on an irradiated area of the object 24 being treated, positions of the dividing mirror 14 and reflecting mirrors 34 and 36 are adjusted by the adjusters 25, 26, 27 and 28 as shown in Figure 1 (not shown in Figure 2). As a result of this compound of the fractional laser beams, the energy density distribution of the laser beam on the irradiated area of the object 24 being treated is made substantially uniform in the above-mentioned x-direction, as will be seen from Figure 3.

In this embodiment, since the fractional laser beams 38 and 40 are irradiated in such a manner that these fractional beams intersect and overlap with each other on the area to be irradiated of the object 24, the original Gaussian energy density distribution of the laser beam taken out from the laser apparatus is shaped into the substantially uniform energy density distribution and hence the applied laser beam can be more uniform than that of the conventional methods.

Additionally, the simplicity of the mirror system including the mirror 14 having the two plain reflecting surfaces 30 and 32 and the plain reflecting mirrors 34 and 36 for compounding the fractional beams leads to an inexpensive construction.

A second embodiment of the present invention as shown in Figure 4 comprises a pair of reflecting mirrors 42 and 44 for compounding fractional beams, each having a cylindrical concave reflecting surface of second degree different from the plain reflecting surfaces of the first embodiment. Except for the above, this embodiment is quite similar to the first embodiment.

In the second embodiment, fractional laser beams 46 and 48 reflected at the concave surfaces 42 and 44 take the form of a semi-elliptical configuration which results from compression in the chord direction of a semicircle, and overlap with each other on an object 24 being treated, having a substantially rectangular cross-sectional configuration as shown in Figure 7. The applied laser beam has a substantially uniform energy density distribution in x-direction and is sufficiently narrow in y-direction, offering a high energy density distribution.

Because of the fractional laser beams focused or converged by the concave reflectors, the applied laser beam can have a high energy with a laser apparatus of a relatively low output.

A third embodiment of the present invention as shown in Figure 8 comprises a regular pyramid-like mirror 58 for dividing the original laser beam 12 and having four plain reflecting surfaces 50, 52, 54 and 56, and four plain mirrors, 60, 62, 64 and 66

arranged correspondingly. Except for the above, this embodiment is quite similar to the first embodiment.

In this embodiment, a laser beam 12 is centered with the apex of the regular pyramid-like mirror 58, and a high energy is concentrated to corners of a square region 68 (Figure 9). Accordingly, the fractional laser beams intersect with each other and are compounded on an area to be irradiated of the object 24 being treated to form an applied laser beam having a cross-sectional configuration as shown in Figure 9. The applied laser beam has substantially uniform energy density distributions in both the x-direction and y-direction within the square region 68.

In place of the plain reflecting mirrors for compounding the fractional laser beams, this embodiment may be modified to include reflecting mirrors each having a concave reflecting surface of second degree to raise the energy density for laser beam treatment.

In the foregoing embodiments, the reflecting mirrors for compounding the fractional beams were described and illustrated as each having a plain surface or a concave reflecting surfaces of second degree. Alternatively, a reflecting mirror as shown in Figure 10 having a curved reflecting surface with curvatures in θ_1 and θ_2 directions which are denoted by radii of curvature R_1 and R_2 , respectively, may be used for attaining similar effects.

The mirror 14 for dividing the original laser beam into two fractional beams having plain reflecting surfaces as explained with reference to the foregoing embodiments may be so modified as to have a concave reflecting surfaces 70 and 72 of second degree as shown in Figure 11, thereby providing ability to focus or converge the respective fractional laser beams.

Obviously, a dividing mirror having convex reflecting surfaces 74 and 76 may be used, as shown in Figure 12, in which the fractional laser beams are once diverged by the convex reflecting surfaces and then reflected and compounded by means of concave reflecting mirrors.

Also, the mirror 58 for dividing the original laser beam into four fractional beams having plain reflecting surfaces as explained with reference to the foregoing embodiment may be so modified as to have concave reflecting surfaces 80, 82, 84 and 86 as shown in Figure 13 or convex reflecting surfaces 90, 92, 94 and 96 as shown in Figure 14.

Experimentally, the surface of a carbon steel containing 0.44% carbon was scanned with a laser beam as shown in Figure 15 to quench the carbon steel surface by using, as an example, a continuous 2 kW CO₂ gas laser beam of 30 mm in diameter with a Gaussian energy density distribution, as a heat source. The laser beam was scanned at a speed of 3 m/min. After quenching, the carbon steel standing for an object 24 to be treated was cut on XVI-XVI line to expose a hardened region 100 as shown in Figure 116, which region was of a hardness of above Hv 550 with a depth of 0.4 mm. Thermal treatment efficiency (area of hardened surface/time) was approximately doubled as compared

with a process utilizing a usual laser beam of a Gaussian energy density distribution to harden a region of 0.4 mm depth, and irregularity in hardened depth was minimized. In Figure 15, the reference numeral 110 is used to designate in general the compounding reflecting mirror position adjusters 25, 26 and 27 shown in Figure 1.

This embodiment can afford to provide an apparatus for laser treatment easily providing an energy density distribution suitable for thermal treatments by merely attaching a head 11 including dividing and compounding mirrors and integrated by a protective cover or housing 13 to a conventional laser treatment apparatus specialized for welding.

As described above, according to the present invention, in a laser treatment method in which a laser beam is irradiated on an object to be treated, the laser beam is divided into a plurality of fractional laser beams, and the respective fractional beams are reflected toward and simultaneously irradiated on an area to be irradiated of the object being treated after being compounded such that the energy density distribution on the irradiated area is made uniform in at least one direction. Accordingly, the laser beam utilized for treating the object has a uniform energy density distribution, and when applied to thermal treatments it can efficiently form thermally treated layers of a uniform depth and stabilize the quality of the treated region.

Since an apparatus for laser treatment according to the present invention comprises a dividing mirror for dividing a laser beam into a plurality of fractional beams and compounding reflectors for reflecting the respective fractional laser beams to simultaneously irradiate them on an area to be irradiated of an object being treated after compounding the fractional laser beams such that the energy density distribution on the irradiated area is made uniform in at least one direction, the apparatus can attain an additional advantage of being more durable than a focusing system using a lens made of potassium chloride even when used with a large power laser beam.

45 CLAIMS

1. A method of treating an object by a laser beam in which the object to be treated is irradiated by the laser beam, comprising the steps of:
50 emitting the laser beam from a laser apparatus; dividing said laser beam into a plurality of fractional laser beams; and
irradiating said plurality of fractional laser beams on an area to be irradiated of the object being treated after compounding said fractional laser beams such that the energy density distribution on the irradiated area is made substantially uniform in at least one direction.
2. An apparatus for treating an object by a laser beam comprising:
means for generating a laser beam;
means for dividing the laser beam into a plurality of fractional laser beams; and
means for irradiating said plurality of fractional laser beams on an area to be irradiated of the ob-

ject being treated after compounding said fractional laser beams such that the energy density distribution on the irradiated area is made substantially uniform in at least one direction.

- 70 3. A laser beam treatment apparatus according to claim 2, wherein said laser beam dividing means comprises at least two reflecting surfaces each disposed at a predetermined angle with respect to the laser beam incident thereto to reflect the incident portion of the laser beam in a predetermined direction.
4. A laser beam treatment apparatus according to claim 3, wherein each of said reflecting surfaces comprises a plain reflecting surface.
- 80 5. A laser beam treatment apparatus according to claim 3, wherein each of said reflecting surfaces comprises a curved reflecting surface.
6. A laser beam treatment apparatus according to claim 5, wherein said curved reflecting surface is of a curved surface of second degree.
7. A laser beam treatment apparatus according to any one of claims 2 to 6, wherein said fractional beam compounding means comprises the same number of plain surface reflecting mirrors as that of 90 said fractional laser beams.
8. A laser beam treatment apparatus according to any one of claims 2 to 6, wherein said fractional beam compounding means comprises the same number of concave surface reflecting mirrors as 95 that of said fractional laser beams.
9. An apparatus for treating an object by a laser beam in which the object to be treated is irradiated by the laser beam, comprising:
a laser for generating the laser beam;
- 100 a housing having a laser beam inlet opening and a laser beam outlet opening;
a mirror having two plain reflecting surfaces and disposed within said housing with a ridge line between the two plain reflecting surfaces centered
- 105 with the cross-sectional area of the laser beam led to said housing through said inlet opening so as to divide said laser beam into two fractional laser beams and reflect them in predetermined directions, respectively;
- 110 two cylindrical concave surface mirrors each having a curved reflecting surface of second degree for reflecting each of said two reflected fractional laser beams and adjustably disposed within said housing; and
- 115 two adjuster means disposed within said housing and operatively connected to said two concave surface mirrors, respectively, to adjust locations of the associated cylindrical concave surface mirrors such that the respective fractional laser beams
- 120 reflected from the respective concave surface mirrors are focused on an area to be irradiated of the object being treated.
10. A method of treating an object with a laser beam substantially as hereinbefore described with
- 125 reference to Figures 1 to 3, or Figures 4 to 7 or Figures 8 and 9, or Figure 10, or Figure 11 or Figure 12, or Figure 13, or Figure 14 or Figures 15 and 16.

11. A laser beam treatment apparatus substantially as hereinbefore described with reference to Figures 1 to 3, or Figures 4 to 7, or Figures 8 and 9, or Figure 10, or Figure 11 or Figure 12, or Figure 13, 5 or Figure 14 or Figures 15 and 16.

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